Application Note:

Interline Image Sensor

Photodiode Charge Capacity and Antiblooming

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1. Introduction to Interline Charge Capacity and Antiblooming

This document describes the photodiode charge capacity and antiblooming properties of monochrome interline image sensors with vertical overflow drains (VOD). It also includes the procedure used to set the photodiode charge capacity and to measure the antiblooming.

Interline sensors with vertical overflow drains allow the antiblooming factor and the photodiode charge capacity to be set by selecting the substrate voltage. There is a trade-off between the antiblooming factor and the capacity, where increasing the substrate voltage increases the antiblooming and decreases the capacity. The specification of the substrate voltage is given to simultaneously satisfy a minimum antiblooming factor and a minimum capacity. Due to the variation from device to device, the substrate voltage is specified for each device to obtain the tightest possible trade-off between the antiblooming and the capacity.

2. Procedure to Set Substrate Voltage for Photodiode Charge Capacity

If the photodiode charge capacity of the device is defined as Q_{sat} (electrons), then the substrate voltage is set to allow Q_{sat} to collect in the photodiode, averaged over the image area. All excess electrons should go over the vertical overflow drain and into the substrate.

Before setting the substrate voltage, the charge-to-voltage ratio, or sensitivity *S*, must be known to determine the output in electrons. The method to set the substrate voltage is to illuminate the sensor such that the photodiodes are saturated at a low substrate voltage (8 V). Then the substrate voltage is increased until the output decreases to SQ_{sat} , averaged over the image area. This substrate voltage setting will give the maximum amount of antiblooming protection while maintaining the desired charge capacity. Due to the saturation nonlinearity of each pixel, and the variation of the saturation from pixel to pixel, the device will have an output saturation nonlinearity in the top 10 to 20% of the output, as schematically shown in Figure 1. See the references for more information on the nonlinearity near saturation.

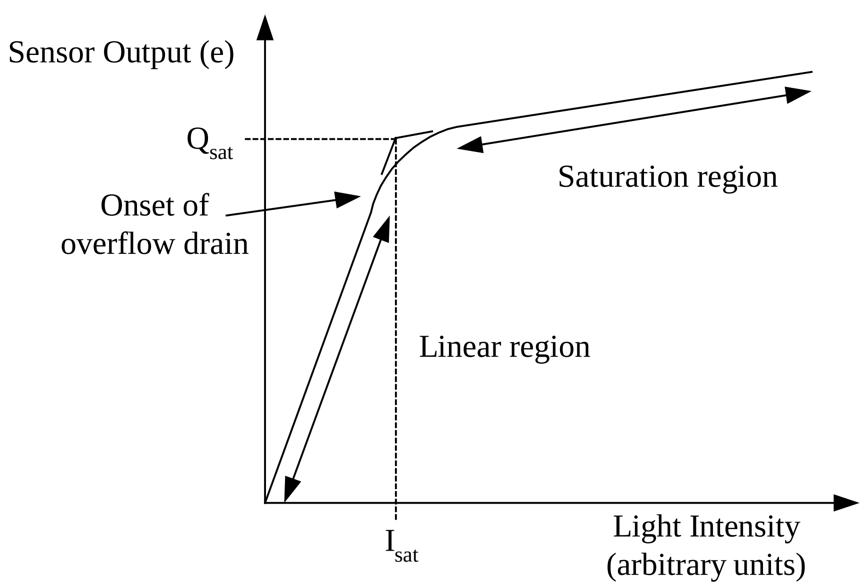

Figure 1 - Sensor output vs. incident light intensity.

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3. Description of Blooming

Blooming occurs when the charge capacity of the vertical CCD (VCCD) is exceeded. The charge spills up the VCCD opposite the direction of charge transfer. There are several factors that contribute to blooming. One factor is the resistance of the VOD. When the current going through the VOD becomes sufficiently high, the effective capacity of the photodiode becomes larger than the VCCD capacity. Another factor is smear. When light directly enters the VCCD, charge is generated on top of what is already present in the VCCD. Therefore, a sensor with lower smear will have better antiblooming. A final factor is the charge collected during the photodiode transfer time. The potential of the transfer gate is below the VOD during the photodiode transfer time (when the appropriate vertical phase is at its high or 3rd level), so excess photodiode charge will flow directly into the VCCD instead of overflowing into the substrate. Therefore, a shorter photodiode transfer duration results in better antiblooming.

4. Antiblooming Measurement Procedure

The measurement of the amount of antiblooming protection is not an exact process. This is because the light levels needed to cause blooming are very high. Lens flare and random scattering of light in the illumination optics makes observation of the onset of blooming difficult. The general procedure is to focus a spot of light onto the sensor with a size that is 10% of the vertical height of the sensor. The light level I_{sat} needed to saturate the output is found first. Then the illumination is increased until blooming of the VCCD causes the spot size to increase a specified amount in the vertical direction. This blooming light level is I_{bloom}. The antiblooming factor X_{ab} is then defined as

$$X_{ab} = \frac{I_{bloom}}{I_{sat}} . \qquad (1)$$

Antiblooming factors are at least 100 times the saturation level.

4.1 Operating Parameters

The device is operated with voltages and timings at their nominal values. The substrate voltage is set for the target photodiode charge capacity. The device is operated without the electronic shutter, with the integration time equal to the frame readout time.

4.2 Light Source

The light source is a tungsten-halogen projector bulb mounted in a fiber-optic illuminator. The output of the fiber is collimated by a lens, which directs the light through a filter stack. The filters include an infrared cutoff filter (Schott BG-39) and a green bandpass filter (for monochrome sensors). A series of precision calibrated neutral density filters is used to control the intensity.

The filtered light falls on an iris aperture, which is used to adjust the spot size. A camera lens images the aperture onto the sensor, with the lens aperture adjusted to F/4.

4.3 Measurement Procedure

For an intensity in the linear range of the sensor, the spot is focused on the sensor, and the spot size is adjusted. Ideally, the spot size is exactly 10% of the vertical CCD height, but in practice, a spot size of 9% to 11% does not significantly affect the measurement. The focus of the spot should be very good to allow accurate measurement of the spot size.

The intensity of the spot is varied in steps over a range from one half the saturation to over 1000 times the saturation. At each intensity, the size of the spot and the output of the sensor in the spot is measured. When the output of the sensor reaches Q_{sat}, the intensity I_{sat} is recorded. When the sensor is blooming, I_{bloom} is recorded. Then the antiblooming factor is calculated using Equation 1.

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Blooming is determined from the vertical profile through the spot, using an average over the five center columns of the spot. The size of the spot is measured at 90% of the peak, in order to remove lens flare. The sensor is defined to be blooming when the spot size increases by a specified amount. The measurement of the spot size at 90% of the peak is very important for obtaining an accurate antiblooming factor. The digital output of the test system must extend to over the VCCD capacity in order to measure the peak.

5. Example Data

The following data was measured on a typical 7.4-micron pixel monochrome device, the KAI-2093M.

1.1 Antiblooming vs. Capacity

The following data illustrates the trade-off between the antiblooming and photodiode charge capacity as the substrate voltage is varied.

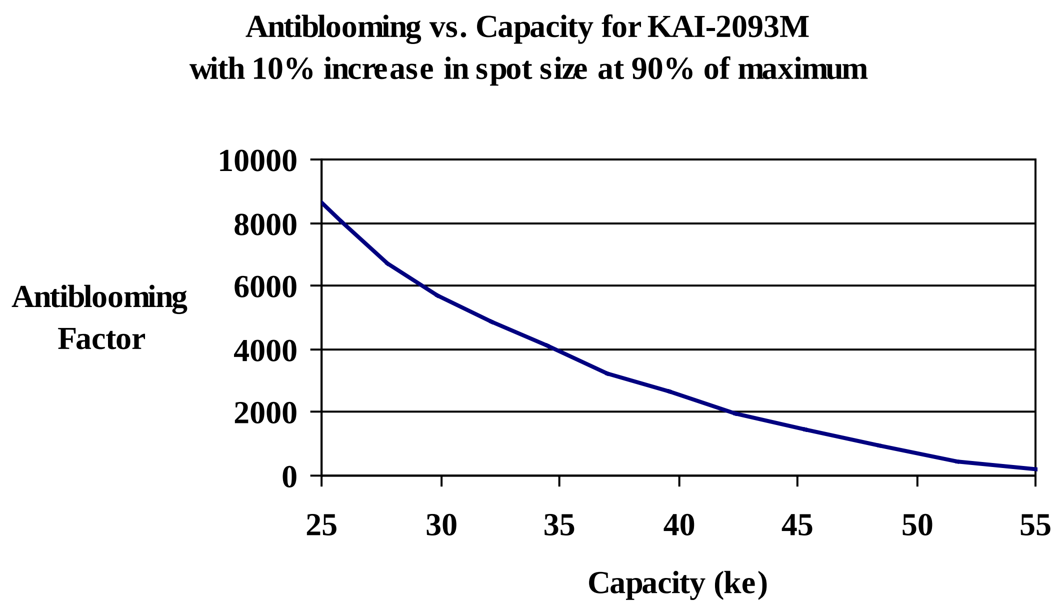

Figure 2 - Antiblooming vs. Capacity for the KAI-2092M with 10% increase in spot size at 90% of maximum

2 References

[1] Eric G. Stevens, "Photoresponse nonlinearity of solid-state image sensors with antiblooming protection," IEEE Trans. Electron Devices, vol. 38, no. 2, pp. 299-302, 1991.

[2] Eric G. Stevens, Yung-Rai Lee, and Bruce C. Burkey, "The effects of smear on antiblooming protection and dynamic range of interline CCD image sensors," IEEE Trans. Electron Devices, vol. 39, no. 11, pp. 2508-2514, 1992.

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